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Analysis of Fabry-Perot Velocimeter Records

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Abstract

Program demonstration and user instructions are presented for *FabryVB5*. This computer program was created for use in analyzing Fabry-Perot interferometer records that detail the velocity time histories of fast moving surfaces. Graphical curves representing peak fringe positions and fiducial timing dots are extracted from a digitized film record or from a CCD digital image. An analysis is demonstrated on a sample velocimeter record along with some mathematical formula and routine operations. Routines used to analyze calibration records on streak camera distortions are illustrated in an appendix. This is a Microsoft Visual Basic ™ version for the PC.

Introduction

To determine velocities of fast moving objects, film records of Doppler shifted interference fringes are obtained from the surface reflected laser light.[1] Experiments performed at the Lawrence Livermore National Laboratory (LLNL) utilize a Many Beam Fabry Perot Velocimeter to acquire velocities from various positions on a given surface.[2] Several of these five beam velocimeters are used at LLNL diagnostic facilities at Livermore and Nevada. Laser beams that reflect from five separate surface positions are multiplexed through a single interferometer, and the associated optics (see Fig. 1), to form five interference fringes which are recorded on separate electronic streak cameras. A single recorded image is shown in Fig. 2 where the camera sweeps in time along the horizontal direction from left to right. Interference fringes are measured to calculate the velocity history.

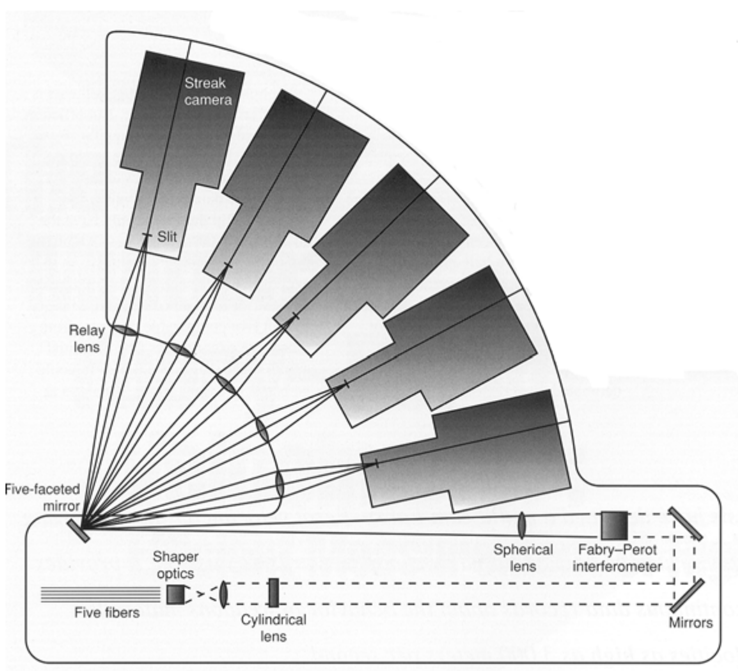

Figure 1. Many Beam Velocimeter

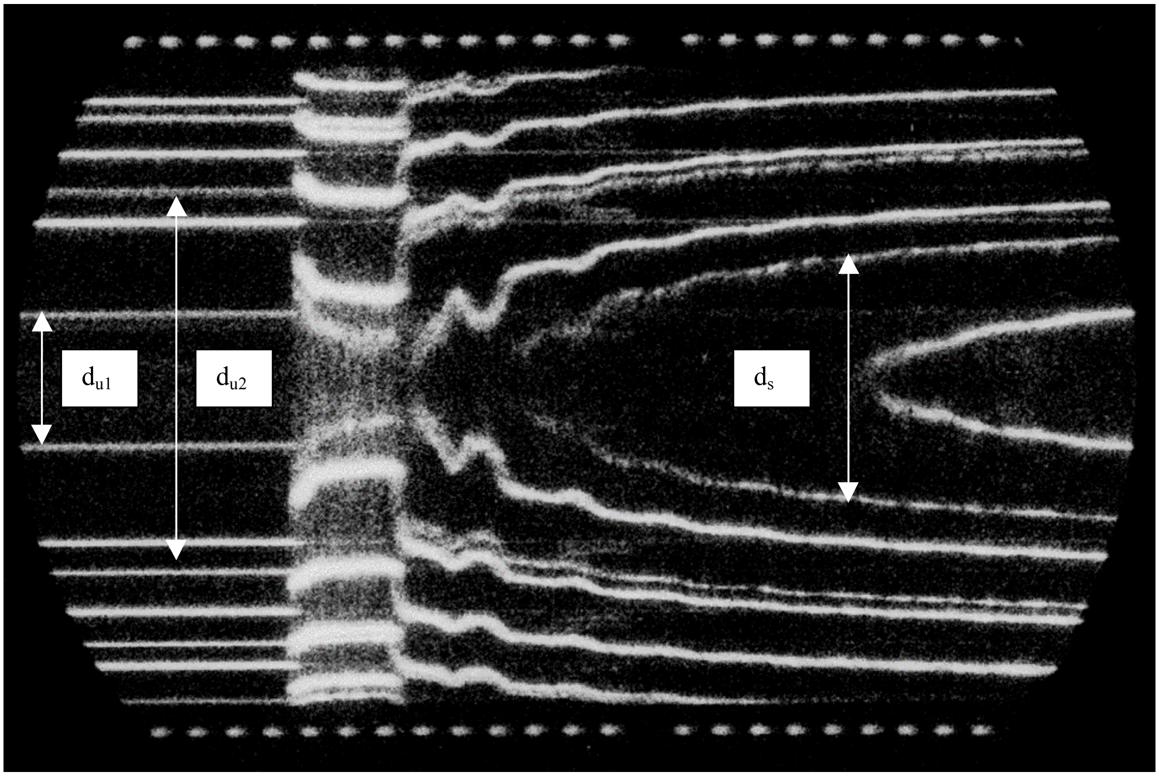

Figure 2. Sample (Double Cavity) Velocity Fringe Record

The straight-line fringes on the left are called UN-Doppler shifted lines (light) while the curvy lines on the right are called Doppler shifted lines. The program operates on both sets of these lines to calculate velocity using the following formula.

(1) $V = (c\lambda/4h)(i+\delta)$.

Where $\delta = (d_s^2 - d_{u1}^2)/(d_{u2}^2 - d_{u1}^2)$.

The subscript using *s* represents a Doppler shifted line and the subscripts using *u* are UN-Doppler shifted lines. The *d* symbols are diameters measured vertical across fringes where subscripts *1* and *2* are respective inner and outer adjacent fringe sets. Laser light traveling with velocity *c* has the wavelength λ. The interference fringe pattern jumps through *i* fringe formations before the velocity change is small enough for new visible fringes to be recorded. The value $(c\lambda/4h)$ is usually called the fringe constant where *h* is the cavity length of the Fabry-Perot interferometer.

Equation (1) is the only formula used by the program to calculate velocities. The program actually uses the radius *r* (rather than diameter *d*) so that each individual curve can be accounted for. A radius is measured at the peak optical density (maximum light exposure) from a given fringe. Other program routines (discussed in Appendix A) use various mathematical corrections to minimize effects of streak camera distortions. These distortions and their effects on velocity and time measurements are presented in a previous paper.[3]

An analysis on the sample of Fig. 2 will demonstrate the various routines available to the user of this program. For clarity, some of the program's mathematical equations will be given. However, most routines will be described conceptually for their functions. This paper is intended to serve as a user manual.

Reading Bitmap Images

We begin an analysis by reading up the sample bitmap image from the *File / Open* menu (see Fig. 3). Filters on the file types can be used to view only bitmap files. Select *Fids* from the *Digitize* menu (see Fig. 4). Now click (and release) on the upper left, then lower right regions of the fids. A rectangle will be drawn around the selected region and curve fit routines will fit to the *X* and *Y* cross sections to find the peak optical density for each fid dot. A poor reading can be removed by selecting *Remove Last Reading* from the *Digitize* menu. The *Digitize* menu pops up with a right mouse click or by using normal menu selection.

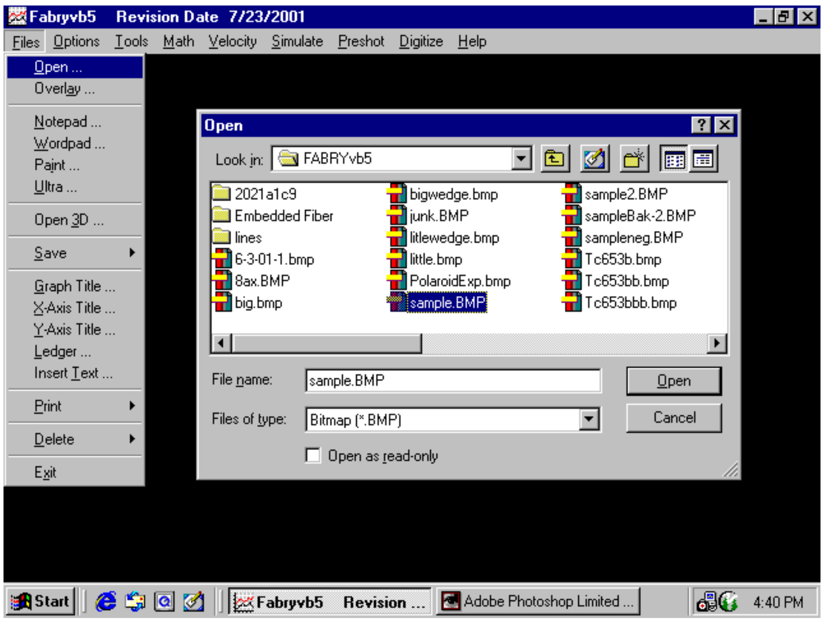

Figure 3. Opening a Bitmap File

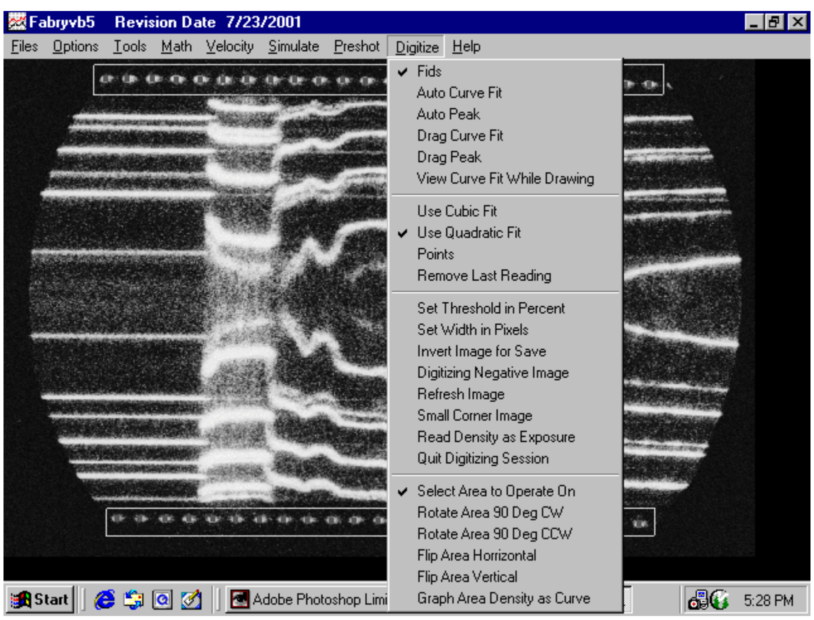

Figure 4. Reading the Fids

Adjustments on *Threshold* and *Width* can be made from the *Digitize* menu to optimize readings. Default threshold is set at 2% (of maximum density) and default width is set at 10 pixels. Set the width to match the fid width or fringe broadness that is being read.

Once the top and bottom fids are read, we read the UN-Doppler fringes. *Select Auto Curve Fit* for easy to read fringes. The *Auto Peak* function is more robust for weaker fringes. These two functions operate from mouse clicks on the beginning and end points of a fringe. Both *Curve Fit* functions mathematically fit a curve to the fringe's cross section profile of optical density. This fit can be seen by selecting *View Curve Fit While Drawing* (see Fig. 5) from the *Digitize* menu. Do not use this function during a reading that will be saved. This function allows the user to view a curve fit for proper selection of the *Width* and *Threshold* settings.

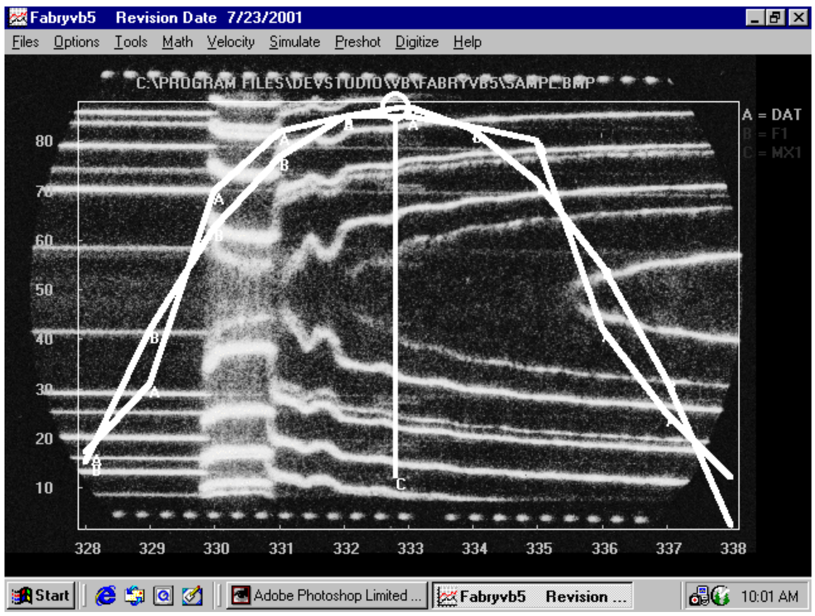

Figure 5. View Curve Fit While Drawing

The most difficult fringes can be read using the *Drag* functions. *Drag Curve Fit* produces a smoother read but the *Drag Peak* can read weak and broken fringes. Both *Drag* functions work well when there are neighboring fringes that are very close to each other. The *Points* function can be used to select individual points to be saved as a curve. Points are recorded exactly at each mouse click and are not curve fit to a peak. The same functions just described are also used to read Doppler shifted lines. Lines or fids can be read in any order. The user can choose either *Quadratic* or *Cubic* curve fit by selection from the *Digitize* menu. Images can also be saved as negatives and then read back up for analysis. When reading a negative image, the user must select *Digitizing Negative Image* from the menu.

Selecting *Refresh* reads the current *clean* image back up without clearing out any data that has been acquired.

Choosing *Read Density as Exposure* converts all pixel depth values from density to exposure while a reading is in process. This has the effect of sharpening peak regions relative to low exposure regions. Its usefulness can only be found by trial and error. An optical density step wedge curve (named *wedge.ult*) must be provided and can be read from film records using the *Select Area to Operate On* function followed by selection of the *Graph Area as Density* function. Flip and Rotation functions are provided for simple orientation of images. Once all fringes are read, select *Quit Digitizing Session* from the menu.

Analyzing Records

Selecting *Quit Digitizing Session* quits digitizing and reads up a binary file with the *.ult* extension (see Fig. 6). The fringe file in the background was just read from the bitmap image. Selecting *Small Corner Image* from the *Digitize* menu can bring up a small bitmap image in the upper left corner. Selecting again removes the small image.

We begin the analysis by selecting some user options from the *Velocity Analysis Options* menu. Fig. 6 shows some choices selected for a typical analysis. The first block of options allows user control on cavity sorting, velocity jump selection and double record analysis. Selecting *Single Record Auto Analysis* starts the actual analysis.

Selecting the option *Interrupt After Cavity Sort* allows the user to inspect program results on interferometer cavity sorting before allowing the program to proceed through the remaining analysis. If something is wrong, the user can fix the problem and then proceed by re-selecting *Single Record Analysis*. Selecting *STOP Auto Analysis* aborts the analysis.

The program typically determines velocity jump conditions automatically from two interferometer cavity lengths. Without a double cavity interferometer, the user must know the actual velocity at surface jump off within half of the fringe constant. When a double cavity is used, then the user must know the true jump velocity within a span of several fringe constants. By overlaying several possible solutions and choosing a velocity with common solutions from the two cavity lengths, the program can usually choose the correct velocity curve.

The second block of options controls the use of distortion correction curves. Selecting *Skip Un-Distort* causes the program to skip all distortion corrections, including the use of top and bottom fids for corrections. The third options block selects various routines that the program performs to determine the quality of a completed analysis. Choosing the options shown in Fig. 6 is a good first choice for performing an analysis.

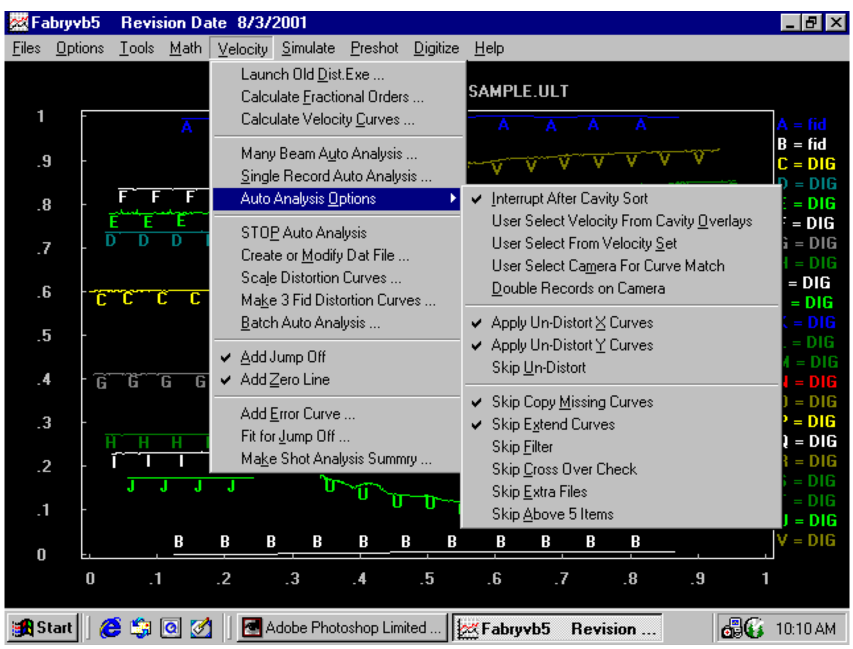

Figure 6. Velocity Analysis Options

Selecting *Single Record Auto Analysis* brings up the *sample.dat* file (see Fig. 7) to be edited for the auto analysis routines. After scaling the data and performing distortion corrections, the program separates the double cavity record into two separate files named *sample.ca* and *sample.cb*.

A set of velocity curves (*sample.cav* and *sample.cbv*) is calculated from each file and the two sets are overlaid (see Fig. 8). A set of four *nearest matching* velocity curves is selected from this overlay and saved in the file *sample.mat*. If the previously mentioned options are selected, a single *nearest match* velocity curve is saved as *sample.udv*.

Should the user choose the *User Select Velocity From Cavity Overlay* option, then the program would allow the user to select from the overlay of *sample.cav* and *sample.cbv*. The *User Select From Velocity Set* option allows the user to choose from the four curves in the file *sample.mat*. The *User Select Camera For Curve Match* option lets the user overlay a previously determined *correct* velocity curve for matching. In this case, the current record to be analyzed must be a single cavity record.

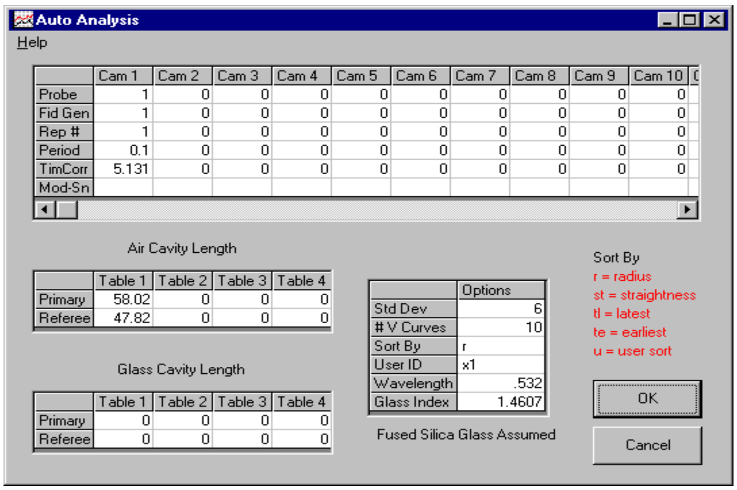

Figure 7. Editing *sample.dat* for the Auto Analysis Routines

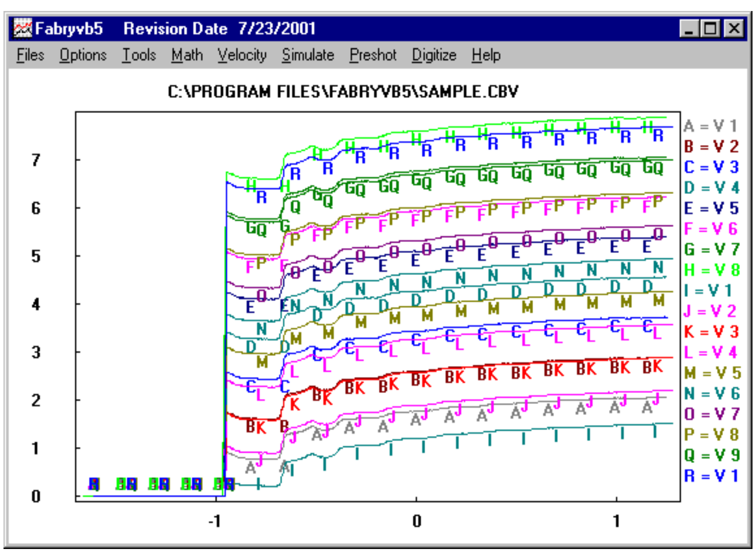

Figure 8. Overlay of *sample.cav* and *sample.cbv* Curve Sets

The final velocity curve is plotted along with an error curve (see Fig. 9). The program multiplies estimated error values by 100 so that they can be plotted along with the velocity curve. Error values are calculated by applying partial derivatives to Equation 1 (which is just a constant multiplied by the variable δ). Replacing each diameter *d* in δ with its radius *r* and setting this equal to a function *F*, we get Equation 2.

(2) $$F = (R^2 - r_1^2)/(r_2^2 - r_1^2).$$

Where *R* is a Doppler shifted fringe (variable) and the *r's* represent UN-Doppler shifted fringes (constants). Summing up the partial derivatives and replacing each differential with an incremental error (Δ) yields an approximate to the variance of *F* (see Equation 3).

(3) $$\Delta F^2 \approx [\Delta R^2/(r_2^2 - r_1^2)]^2 + \{ [\Delta r_1^2(R^2 - r_2^2)]^2 + [\Delta r_2^2(r_1^2 - R^2)]^2 \} / (r_2^2 - r_1^2)^4.$$

The program calculates an error Δ as being equal to one standard deviation from the average value. Since *R* is a variable, its error is estimated as $\Delta(R_2^2 - R_1^2)$ where $(R_2^2 - R_1^2)$ is a constant. The error curve *B* in Fig. 9 is calculated by summing the variances of all fringes that are read to get a single velocity curve. Errors from a two-fringe average will be approximately $2^{-1/2}$ times the errors for a single fringe. The downward steps in the error curve occur where the number of fringes (that are read) increase for a given time domain.

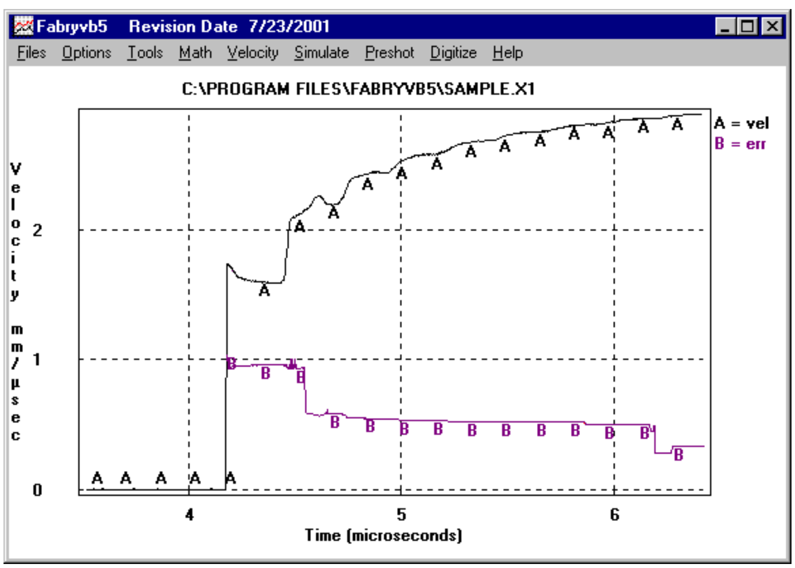

Figure 9. Velocity and Error Curves

A summary text file is created for the user to access more information on the quality of an analysis. Some important tabulation from the text file is shown in Table 1 and Table 2. Table 1 lists the averaged radius-squared differences for UN-Doppler shifted fringes (curves 0a-1a) and for Doppler shifted fringes (curves 0b-3b). *Totsize* is the number of data points in the curve and *Rsqsize* is the number of points calculated for radius squared differences. The difference between *Totsize* and *Rsqsize* are points outside of overlap regions in the shared time domain. *Percent* is the standard deviation divided by the average and then expressed in percent.

Table 2 lists statistics on *Crossover* points. These are points where UN-Doppler lines (or their extensions) cross Doppler lines and their computed velocities should be exactly equal to an integer number of fringe constants. The error column tabulates these differences and it is an excellent overall check on the accuracy of velocity calculations. The largest errors will occur where the changing velocity jumps, causing a large difference in velocity for a small difference in time. The user can control sensitivity of crossover point calculations to the velocity slope by going to *Tools / Curve Operations / Set Maximum Slope*. Selecting *Notepad* from the *File* menu can access the text file discussed above.

CURVE	AVERAGE	STD DEV	PERCENT	TOTSIZE	RSQSIZE
C = 0a	0.0556	0.0006	1.0	207	192
D = 0a	0.0566	0.0005	0.9	206	175
E = 1a	0.0556	0.0006	1.1	191	191
F = 1a	0.0566	0.0005	1.0	175	175
G = 0b	0.0555	0.0004	0.7	171	156
H = 0b	0.0561	0.0005	0.9	163	145
I = 1b	0.0555	0.0007	1.2	587	156
J = 1b	0.0561	0.0007	1.3	581	145
K = 2b	0.0562	0.0026	4.7	666	525
L = 2b	0.0570	0.0016	2.8	683	529
M = 3b	0.0564	0.0033	5.9	657	655
N = 3b	0.0563	0.0022	3.9	659	658

Table 1. Radius Squared Differences

CUR-1	CUR-2	X	Y	VELOCITY	ERR(VEL)
C = 0a	I = 1b	.4738049	.7317749	2.745767	3.110778E-03
C = 0a	I = 1b	.4783973	.7317749	2.753166	4.288502E-03
C = 0a	I = 1b	.5449615	.7317749	2.759646	1.076795E-02
C = 0a	I = 1b	.5620036	.7317749	2.764953	1.607492E-02
D = 0a	J = 1b	.4487458	.2684139	2.747039	1.838351E-03
D = 0a	L = 2b	-.6470613	.2684139	2.076888	1.522964E-02
E = 1a	K = 2b	.3891999	.8306894	2.733716	1.516213E-02
E = 1a	K = 2b	.4408722	.8306894	2.74801	8.678916E-04
F = 1a	L = 2b	.435573	.1680038	2.748459	4.187901E-04
F = 1a	L = 2b	.5534215	.1680038	2.757058	8.180824E-03

Table 2. Crossover Point Statistics

Back Calculating Fringes from a Velocity Curve

Fringes can be *back calculated* from a velocity curve using routines in the *Simulate* menu. This is very useful for checking the correctness of cavity sorting. The calculated fringes should exclusively overlay onto the original bitmap image. If there are extra calculated fringes or if there is a shortage of calculated fringes, then an error has occurred in the cavity sorting.

For back calculation, we must extract the *fractional orders* from the original fringe curves. First, read up the file *sample.cb* and select *Tools / Evaluations / Fractional Order*. Next, do the same for the *sample.ca* curve. We have now loaded up values of *fractional orders* for the primary and referee cavity fringes respectively. Now, read up the *sample.udv* curve and select *Simulate / Settings* from the menu. Figure 10 shows the dialog for input on simulations. The user must type in values for the two cavity lengths, the fid period and optical parameters. Clicking *OK* will calculate the fringe constants. Clicking *Simulate / Make Fringes* will calculate the fringes.

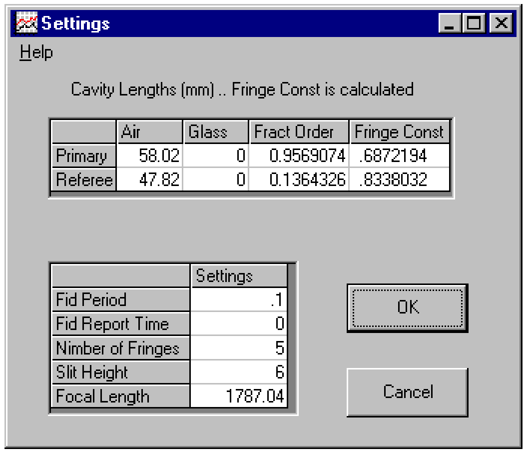

Figure 10. Dialog for Input on Simulations

The program overlays the two calculated fringe files *samplesim1.sim* and *samplesim2.sim*. These files are for the primary and referee cavities respectively.

Finally, read up the original bitmap file and select *File / Overlay* to overlay either (or both) of the simulated fringe files. Figure 11 shows the overlaid fringes after adjustments have been made on magnification and translation. To translate a fringe file, select *Simulate / Move X,Y Overlay* from the menu and then click and drag with the mouse. Similar operations will perform *Stretch X* and *Stretch Y* adjustments. A small circle near the center will indicate where to click for a new translation move. Small differences between the overlays and the original image occur where distortions are in the bitmap image. The main purpose is to account for all fringes in the calculation.

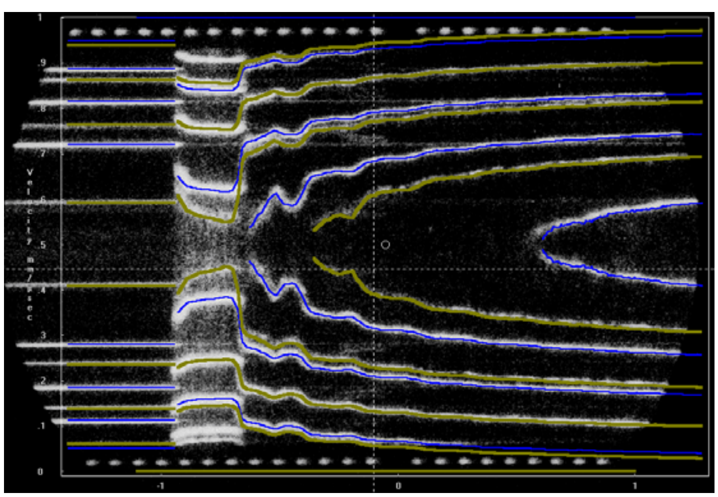

Figure 11. Fringe Simulation Overlay

Many Beam Velocimeter Records

All of the routines discussed so far also apply to analyzing records produced by the *Many Beam Velocimeter*. The only difference between a *Many Beam* analysis and a *Single Record* analysis is that the user will select *Many Beam Auto Analysis* instead of *Single Record Auto Analysis* from the *Velocity* menu. The same dialog will appear as before and the user must fill in all applicable fields. Figure 12 shows the input dialog that is completed for a *different* 10 beam record analysis.
Note that the table-2 cavity length data includes a 20.82-mm thick glass insert, which causes one side of the primary cavity to become a referee cavity of increased optical thickness. The air thickness for the referee cavity is just the air thickness of the primary cavity (58.06-mm) less the glass thickness.

Velocities are still calculated from Equation (1). The cavity thickness h is automatically replaced with $h + T(n - \lambda dn/d\lambda)$, where n is the index of refraction for a glass insert of thickness T (see Ref. 4).

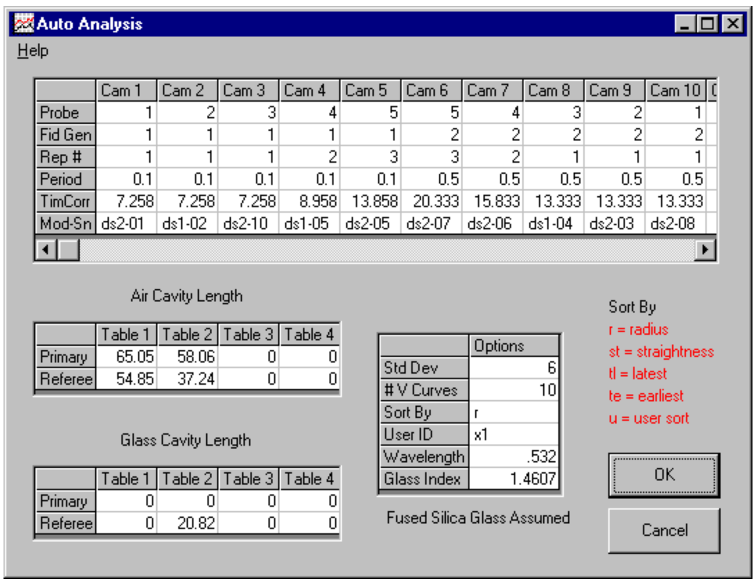

Figure 12. Editing *sample.dat* for Many Beam Auto Analysis

More beams can be added up to a total of 20 cameras. When more than 20 beams are needed, double records can be utilized for each camera to increase the total number of beams to 40 on a four table *Volicimeter*. Multiplexing two beams onto one camera is accomplished by an optical technique that projects one beam onto the upper half and another beam on the lower half of single slit.

The analysis program recognizes double record data when the user selects *Double Records On Camera* from the *Velocity / Auto Analysis Options* menu. Examples and instructions on file naming conventions for *Many Beam Records* and *Double Records* are found in the *Help* menu on *Record Analysis* and on *Double Records*.

After completing the analysis of all 10 records, the user can select *Velocity / Make Shot Analysis Summary* to summarize all data for the record set. Data are extracted from each of the camera text files and are tabulated into summary tables.

Selecting *Velocity / Batch Auto Analysis* allows the user to re-calculate the velocity on all fringe curves. This is useful when a new parameter (such as interferometer cavity length or laser wavelength) is to be used to re-calculate the original data.

Distortion correction curves can be applied during an analysis by pre-selecting *Apply Un-Distort X Curves* and/or *Apply Un-distort Y Curves* from the *Velocity / Auto Analysis Options* menu. The *X-axis* is time and the *Y-axis* is space on the fringe file *sample.ult*.

Distortion correction curves that are currently available are approximately one year old and they are expected to degrade over time (see Reference 3). One can evaluate their current effectiveness by comparing velocity errors from the *crossover point* statistics. If the errors are larger for velocities calculated using distortion correction curves then the curves should not be used and new calibrations are needed. Appendix A describes the routines and methods used to create new distortion correction curves.

When using distortion correction curves, it is important to verify that the scanner to be used in obtaining a bitmap image is sufficiently distortion free for the analysis. The film must also be scanned from the emulsion side of the film record, otherwise the top and bottom of the image will be reversed and distortion corrections will be invalid.

Using the Preshot Menu

The *Preshot* menu was created to calculate streak camera set up timing and to create the *sample.dat* file. Users can open *LabView* or *Catalyst* digitizer data files to measure timing information. Reading a *Catalyst* file requires that the executable file *cattext.exe* must reside in the folder containing the *Catalyst* file being read.

Using the input dialog's default setting for minimum volt amplitude will work for most *LabView* or *Catalyst* files. Entering a zero will cause the default setting to be applied for the analysis. Select *Analyze Times* to determine times between the first signal and all later signals. The program's sensitivity to interpreting noise as a signal can be reduced by selecting *Reset Signal Level* from the *Preshot* menu. Again, entering a zero will cause the default setting to be applied.

Selecting *Create / Modify Setup File* from the *Preshot* menu loads up the input dialog shown in Fig. 13.

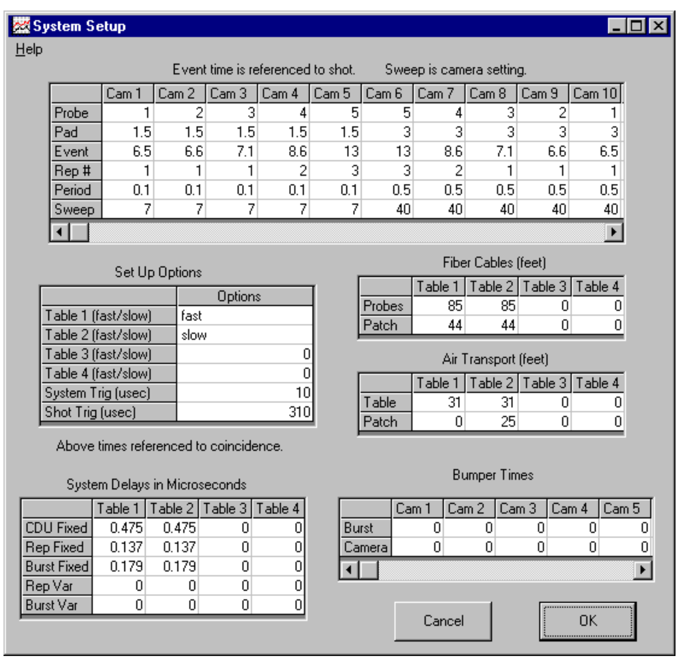

Figure 13. Editing the *sample.set* File

This dialog allows us to create or modify the set up file *sample.set*. All input times are in microseconds. *Pad* (in the first block of Fig. 13) is the time from the first fid dot to the *Event*. *Period* is the time between fid dots and *Report* (the time reference) is the number of dots that are *dimmed* on the fid *burst* (string of dots).

The *Setup Options* block of Fig. 13 allows selection of *slow* or *fast* for the table set up timing. The *fast* set up is required when the camera start times must *float* with the timing jitter of a given fire-set. This option requires that the time between the shot CDU and the streak camera start time must be greater than 1/10 of the streak camera sweep setting. This is necessary because a streak camera trigger time starts the camera streak tube rather than the intensifier tube (which is smaller in diameter). Using the *slow* option only requires that the operator set up enough *Pad* time to compensate for fire-set time jitter. *System Trig* is the timing set up signal sent from the control room and must be at least 300 microseconds earlier than the earliest *Event* time. This allows time for the pulsed laser to be producing useable light. *Shot Trig* is the time that the shot CDU fires the shot.

The *System Delays* box must have values typed in for signal time delays of the shot CDU, the fid *Report* and the fid *Burst*. *Report Var* and *Burst Var* are user input values of the variable delays (signal cables) that are installed into the system signal cables to *zero* out (correct) time delays for a given shot. Other boxes allow input of fiber optic cable lengths and laser air-transport lengths. Delay times are calculated for these values. *Bumper Times* are for trimming delay times during dry times runs, i.e. correcting for individual function times of the fid bursts and streak cameras.

Clicking *OK* will update/create the *sample.set* and *sample.prn* files. A text editor automatically opens the *sample.prn* file onto the monitor screen. This file summarizes all of the set up information.

Selecting *Create Dat File* from the *Preshot* menu causes the program to read data from the *sample.prn* file as input for creating the *sample.dat* file. Once the program opens the input dialog (see Fig. 12) the user must type in the *raw* measured times between the shot CDU and the report for each camera (the *TimCorr* row). The streak camera model/serial numbers should also be typed in. Interferometer cavity lengths for each table that is used must be typed into the appropriate blocks. Clicking *OK* will generate the *sample.dat* file with the appropriate corrections made for system time delays.

Tables 3-5 show the contents of our *sample.prn* file discussed above. Table-3 lists interferometer data and timing corrections on fid report times. Table-4 lists calculated delay times and settings for the streak cameras. Table-5 lists signal cable time corrections along with input from the *sample.set* file. The *sample.prn* file and the *sample.dat* file should be forwarded to the analyst along with the streak camera shot records.

We close with a word on using the mathematical functions and other routines to step through an analysis. Math functions are included in the program to support the analysis routines. Fig. 14 shows the various math functions that can be selected from the menu. Most menu selections begin with an input dialog that explains what it will do and then prompts for whatever input that it needs.

The user can step through a complete analysis by selecting various routines, one at a time. Additionally, any single function (math of otherwise) can be used to perform an operation on the currently opened file. An input prompt will explain what type of file that the function can work on or will open an input dialog with a help menu. The user will then have a choice to continue or to exit the function without doing anything. The *Help* on *Record Analysis* contains step by step instructions for doing this type of analysis.

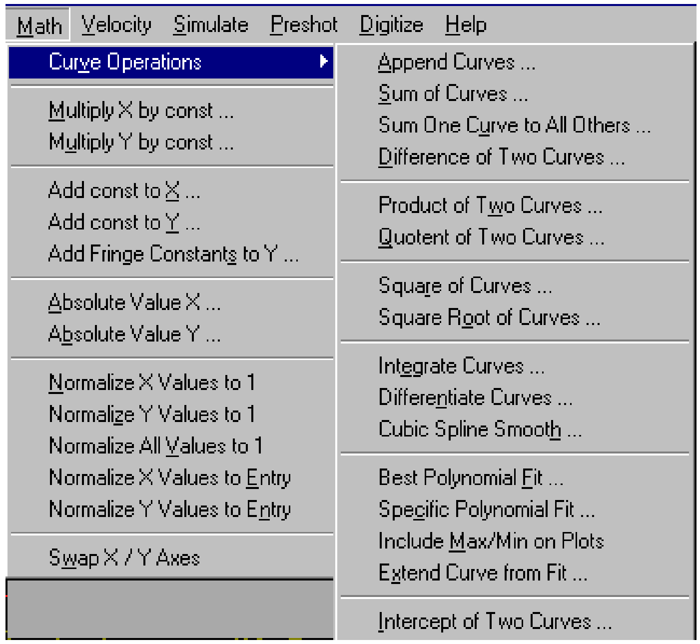

Figure 14. The Math Menu

INTERFEROMETER CAVITY LENGTHS AND FRINGE CONSTANTS

INTERFEROMETER	TABLE	CL AIR	CL GLASS	FRINGE CONST
Primary	1	065.05	000.00	0.6130
Referee	1	054.85	000.00	0.7269
Primary	2	058.06	000.00	0.6867
Referee	2	037.24	020.82	0.5851

FILM RECORD REPORT TIMES REFERENCED TO SHOT CDU OUTPUT

CAMERA	PROBE	RAW REP	CORRECTION	CORRECTED REPORT	MOD-SN
01	01	006.960	0.298	007.258	ds2-01
02	02	006.960	0.298	007.258	ds1-02
03	03	006.960	0.298	007.258	ds2-10
04	04	008.660	0.298	008.958	ds1-05
05	05	013.560	0.298	013.858	ds2-05
06	05	020.060	0.273	020.333	ds2-07
07	04	015.560	0.273	015.833	ds2-06
08	03	013.060	0.273	013.333	ds1-04
09	02	013.060	0.273	013.333	ds2-03
10	01	013.060	0.273	013.333	ds2-08

Table 3. Part of the *sample.prn* File

ITEM	DELAY	REFERENCE
System	010.0	Coinc
Shot	310.0	Coinc
Digitizer	275.0	System
Earliest	300.0	System
Latest	338.5	System
Burst-1	003.6	Shot
Burst-2	295.5	System
YAG	040.0	System

CAMERA TRIGGER

(Last two columns..delay & reference..are for Stanford Research boxes)

CAM	DELAY	REFERENCE	DELAY	REFERENCE
01	003.7	Shot	000.1	Burst-1
02	003.8	Shot	000.2	Burst-1
03	004.3	Shot	000.7	Burst-1
04	005.8	Shot	002.2	Burst-1
05	010.2	Shot	006.6	Burst-1
06	302.5	System	007.0	Burst-2
07	298.1	System	002.6	Burst-2
08	296.6	System	001.1	Burst-2
09	296.1	System	000.6	Burst-2
10	296.0	System	000.5	Burst-2

CAMERA REPORT

(Program used latest of shared reports and rounded to nearest period)

CAM	DELAY	REFERENCE	REPORT #	PERIOD	SHOT to REP
01	003.4	Fid Burst	1	0.100	007.1
02	003.4	Fid Burst	1	0.100	007.1
03	003.4	Fid Burst	1	0.100	007.1
04	004.9	Fid Burst	2	0.100	008.6
05	009.3	Fid Burst	3	0.100	013.0
06	017.0	Fid Burst	3	0.500	013.0
07	012.5	Fid Burst	2	0.500	008.6
08	011.0	Fid Burst	1	0.500	007.1
09	011.0	Fid Burst	1	0.500	007.1
10	011.0	Fid Burst	1	0.500	007.1

CAMERA RECORD START

(start = first fid dot) (# dots does not count the report)

CAM	START	REFERENCE	PROBE #	START to REP	# DOTS
01	005.0	Shot	01	002.1	20
02	005.1	Shot	02	002.0	19
03	005.6	Shot	03	001.5	14
04	007.1	Shot	04	001.5	14
05	011.5	Shot	05	001.5	14
06	010.0	Shot	05	003.0	05
07	005.6	Shot	04	002.9	05
08	004.1	Shot	03	002.9	05
09	003.6	Shot	02	003.4	06
10	003.5	Shot	01	003.5	06

Table 4. Part of the *sample.prn* File

CABLE CORRECTIONS AND NEEDED VARIABLE CABLE CHANGES (microseconds)

CAM	DIG	FILM	REPORT VAR	BURST VAR
01	0.338	-0.040	0.338	0.040
02	0.338	-0.040	0.338	0.040
03	0.338	-0.040	0.338	0.040
04	0.338	-0.040	0.338	0.040
05	0.338	-0.040	0.338	0.040
06	0.338	-0.065	0.338	0.065
07	0.338	-0.065	0.338	0.065
08	0.338	-0.065	0.338	0.065
09	0.338	-0.065	0.338	0.065
10	0.338	-0.065	0.338	0.065

INPUT DATA

(Bump times are differences from nominal set up calculations.)

CAM	PROBE	SWEEP	OPTION	PAD	BUMP BURST	BUMP CAM
01	01	07.0	fast	01.5	00.0	00.0
02	02	07.0	fast	01.5	00.0	00.0
03	03	07.0	fast	01.5	00.0	00.0
04	04	07.0	fast	01.5	00.0	00.0
05	05	07.0	fast	01.5	00.0	00.0
06	05	40.0	slow	03.0	00.0	00.0
07	04	40.0	slow	03.0	00.0	00.0
08	03	40.0	slow	03.0	00.0	00.0
09	02	40.0	slow	03.0	00.0	00.0
10	01	40.0	slow	03.0	00.0	00.0

FIBER CABLES (feet)

ITEM	TABLE-1	TABLE-2	TABLE-3	TABLE-4
Probes	085	085	000	000
Patch	044	044	000	000

AIR TRANSPORT (feet)

ITEM	TABLE-1	TABLE-2	TABLE-3	TABLE-4
Table	031	031	000	000
Patch	000	025	000	000

SYSTEM DELAYS (microseconds)

ITEM	TABLE-1	TABLE-2	TABLE-3	TABLE-4
CDU Fixed	0.475	0.475	0.000	0.000
Rep Fixed	0.137	0.137	0.000	0.000
Burst Fixed	0.179	0.179	0.000	0.000
Rep Var	0.000	0.000	0.000	0.000
Burst Var	0.000	0.000	0.000	0.000

Table 5. Part of the *sample.prn* File

Appendix A: Streak Camera Distortion Calibrations

Results of streak camera distortion calibrations can be found in Reference 3. Here, we will describe program routines used to analyze distortion calibration records and to create distortion correction curves.

Fig. A1 shows the reading of a time distortion calibration record where we simply read from top to bottom using the *Fids* selection of the *Digitize* menu.

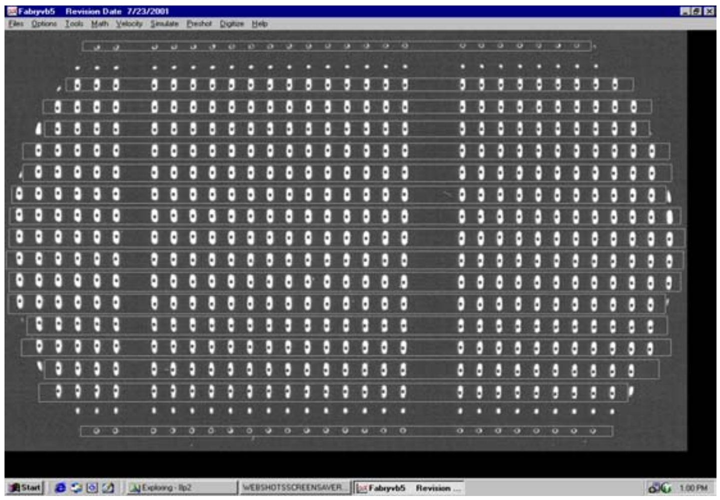

Figure A1. Time Distortion Calibration Record

After quitting the *Digitize* menu, select *Make Undistort X Curve Set* from the *Tools / Fid Operations* menu. The program calculates a time distortion correction file **.xds* where * is the applicable name of the bitmap file. Contents of the **.xds* file are described in Reference 3. Several such files can be averaged by selecting *Tools / Average Many Un-Distort Curve Sets*. Next, we test the averaged correction curve set by reading up the **.ult* file that was created from the original bitmap image. Selecting *Tools / Rename Curves Like Fringe File* will prepare the file for testing.

Select *Options / Un-distort / Do All Above* to perform the standard correction using only the top and bottom fids. Follow this correction by selecting *Apply Un-Distort X Curve Set* from the *Tools / Fid Operations* menu. The resulting *corrected* curve can be evaluated by selecting *Deviation From Nominal X Many Fids* from the *Tools / Fid Operations* menu. The resulting curve is a plot of time errors (*Y*) for the time axis (*X*). If there are *wild points* at the ends of the curves (due to edge distortions of the intensifier) we can remove them by selecting *Max Distortion Or Error* from the *Tools* menu.

Similarly, we create a set of space (*Y-axis*) correction curves from a space distortion calibration record (see Fig. A2). On this record, we must use the *Auto Curve Fit* menu selection to read the lines. Top and bottom fids are read as usual.

To make the space correction curves, select *Make Un-distort Y Curve Set* from the *Tools / Y Axis Operations* menu. To test an averaged set of space correction curves, read up the **.ult* file and select *Tools / Rename Curves Like Fringe File*. Now select *Options / Un-distort / Do All Above* followed by *Apply Un-Distort Y Curve Set* from the *Tools / Y Axis Operations* menu.

Evaluate the *corrected* curve by selecting *Deviation From Nominal Y for Lines* from the *Tools / Y Axis Operations* menu. The resulting curve is a plot of space errors (*Y*) for the time axis (*X*). Make a qualitative evaluation by reading up the corrected (and saved) file followed by selecting *Overlay Nominal X or Y Lines* from the *Tools* menu. This can also be done for a time corrected curve set. Graphical plots of the qualitative overlay can be found in Reference 3. Note that any correction curve set (**.xds* or **.yds)* can be scaled to a different time domain by selecting *Scale Distortion Curves* from the *Velocity* menu.

We check the effectiveness of our space correction curves using velocity calibration records such as that shown in Fig. A3. These types of records are also discussed in Reference 3. We read the calibration record using the *Auto Curve Fit* selection from the *Digitize* menu. Weak lines represent Doppler shifted fringes and bright lines represent UN-Doppler shifted fringes. For the analysis, one must read at least two pair (one pair is a top and bottom fringe set) of UN-Doppler lines and three or four pair of Doppler lines. Read from the middle regions out towards the fids. Outer regions near the fids are usually too weak and crowded for a good analysis. Readings can be in any order but the fids should be read first.

To analyze the resulting **.ult* file, select *Double Records on Camera* and *Apply Un-Distort Y Curves* from the *Velocity / Auto Analysis Options* menu. Now select *Analyze Velocity Calib Curves* from the *Tools / Y Axis Operations* menu.

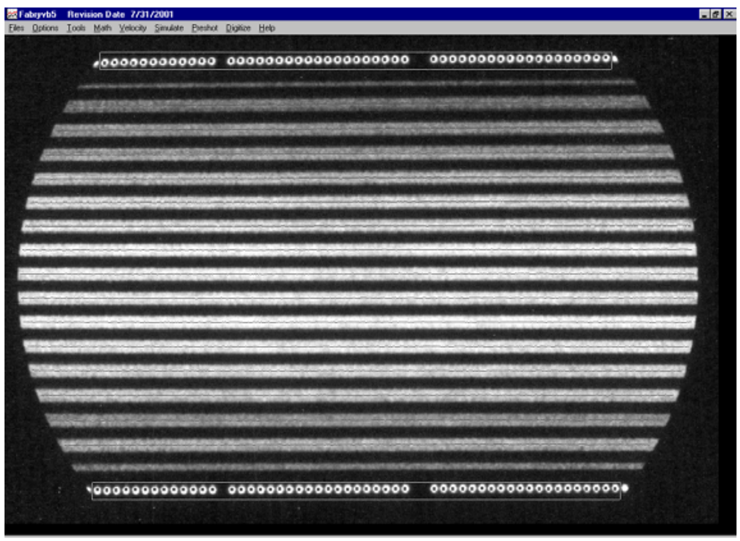

Figure A2. Space Distortion Calibration Record

A series of operations will occur while the screen displays some calculated curves. When the analysis stops, read up the resulting **.txt* file using the *File / Notepad* menu. Discussion and interpretation of this file can be found in Reference 3.

The calibration record shown in Fig. A3 was read with three pair of UN-Doppler lines. Using three pair of UN-Doppler lines, the program can calculate the center of the fringe pattern by using only the top half or the bottom half of a record (see Fig. A3).

(A1) $r = ab/(a - b) - {}^{1}/_{2}(a+b)$.

Equation A1 solves for *r* by using only the parameters *a* and *b*.

When there are only two pair of UN-Doppler lines used, the user must select *Use Auxiliary Record for Centering* from the *Tools* menu before doing the analysis. An auxiliary record is a streak camera photographic exposure of a full fringe pattern (not the top half of one fringe set plus the bottom half of another fringe set). A value for the precise vertical center position of a fringe pattern is required for analysis of any double record.

We end with a word on correcting distortions by using three fids (top, middle and bottom) instead of the full map of fids as described in Reference 3. Distortion correction files can be made from a standard velocity record provided that the three fids have been installed onto the streak camera slit plate.

By selecting *Make 3 Fid Distortion Curves* from the *Velocity* menu, we can create a set of distortion correction curves from the three sets of fid dots. Reference 3 summarizes the effectiveness of this method of distortion correction.

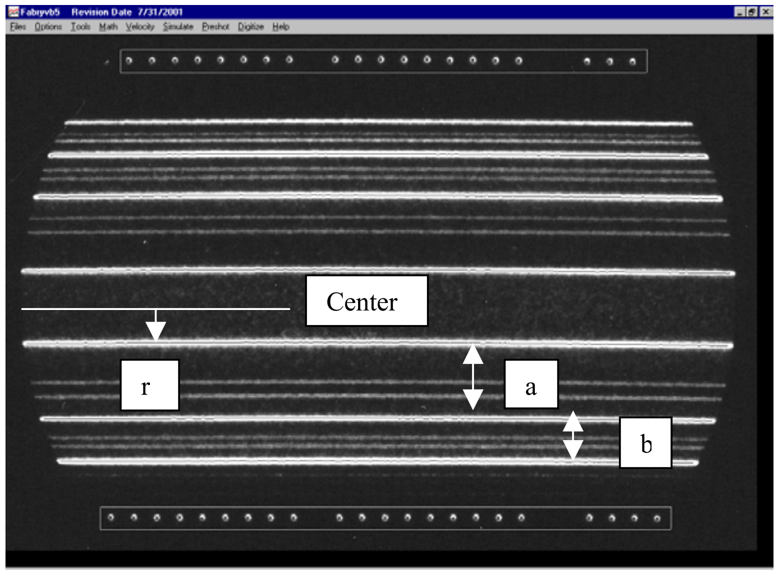

Figure A3. Velocity Distortion Calibration Record

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2. David Goosman, George Avara, Lloyd Steinmetz, Ching Lai, Stephen Perry, "Manybeam Velocimeter for Fast Surfaces", *22nd International Congress on High-Speed Photography and Photonics, SPIE 2869, 1070 (1996).*

3. George Avara, Leland Collins, Anthony Rivera, "Distortion Corrections for the Many Beam Fabry Perot Velocimeter", *UCRL-ID-143225 (March 21, 2001).*

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